APPLIED STUDIES

Residential and Commercial Painters' Exposure to Lead during Surface Preparation

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The California Painters Project was a 2-year intervention research project aimed at preventing lead poisoning among a group of residential and commercial painters in San Francisco, Calif. As part of this project 12 contractors invited project staff to conduct employee exposure monitoring. Twenty-five full-shift samples were collected, with 8-hr TWA results ranging from 0.8 to 550 $\mu g/m^3$ (arithmetic mean: 57 $\mu g/m^3$). Six of the 25 samples (24%) were above the Occupational Safety and Health Administration (OSHA) permissible exposure limit; all of these involved dry manual sanding or uncontrolled power sanding. Fifty-eight 30-minute task-specific samples also were collected. The arithmetic mean concentration results for heat gun use, wet sanding, and open flame burning were all under 10 $\mu g/m^3$; the mean concentration for HEPA-exhausted power sanding was 33 $\mu g/m^3$; dry manual scraping, 71 $\mu g/m^3$; dry manual sanding, 420 $\mu g/m^3$; and uncontrolled power sanding, 580 $\mu g/m^3$. Analysis and modeling based on the 30-min results for dry manual sanding and uncontrolled power sanding indicate that painters' full-shift exposures often exceed 500 $\mu g/m^3$ and the OSHA assigned level of protection for a half-mask air-purifying respirator. These results are cause for concern because both of these surface preparation methods are widely performed wearing half-mask respirators. The data show that HEPA-exhausted power sanding reduces paint dust exposure levels by approximately 80 to 90%. These tools should be more widely promoted as a safer alternative work method.

Keywords: lead exposure, painters, surface preparation, work methods

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Residential and commercial painters often spend a considerable amount of time and effort preparing exterior building surfaces for repainting. Surface preparation means sanding, scraping, burning, or otherwise removing old paint that is peeling or flaking and no longer intact. This ensures that the new primer and paint will form a durable, weather-resistant bond with the surface to which it is being applied. The amount of old paint removed during surface preparation depends on its condition, aesthetic considerations, and the project budget. In some areas the accumulated layers of paint may be completely removed, whereas in other areas the surface may receive only light sanding. The removal of lead paint that accompanies this work is highly irregular and completely incidental to the process of surface preparation.

The exteriors of buildings constructed before 1980,[(1)] and in particular those built before 1950, frequently are coated with one or more layers of lead-containing paint. These buildings include single family dwellings, apartment buildings, schools, day care centers, offices, and retail and commercial establishments.

Where lead paint is present, surface preparation work can produce significant amounts of lead paint dust or fume. Studies have shown that airborne lead levels in excess of 50 $\mu g/m^3$ are generated by power sanding and grinding, dry manual sanding and scraping, heat gun use, and propane torch burning.[(2–10)]

Data on lead poisoning among residential and commercial painters are limited. In part this is because lead-poisoned workers may not exhibit overt symptoms, and blood lead testing is not widespread within the construction industry. The Occupational Safety and Health Administration (OSHA) requirement for blood lead testing in the construction industry did not become effective until 1993 (29 CFR §1926.62). Nevertheless, serious lead poisoning cases have been documented among house painters who conduct surface preparation without adequate protective measures. In a number of studies, sanding, scraping, burning, or sandblasting lead paint resulted in blood lead levels (BLLs) ranging from 70 to 600 μg/dL.[11–14]

State blood lead registries also have identified painters with seriously elevated blood lead levels. A review of data from California's Occupational Blood Lead Registry from 1987 through 1989 showed that applying lead paint or removing it by scraping or sandblasting were the tasks associated with painters' elevated BLLs.[15] In Massachusetts, house and bridge painters comprised 36% of construction workers with BLLs exceeding 40 μg/dL, whereas "deleaders," or residential lead abatement workers who use similar paint removal techniques, accounted for 60%.[16]

This investigation was conducted as part of the California Painters Project, a 2-year intervention research project conducted by the Occupational Lead Poisoning Prevention Program in the California Department of Health Services from spring 1994 to fall 1995. The effort was to design, implement, and evaluate a multidimensional intervention strategy to prevent lead poisoning among a group of lead-exposed painters in the City and County of San Francisco, Calif. Twenty-one established, licensed, residential and commercial painting contractors voluntarily enrolled in this project; altogether, they employed 132 employees doing some surface preparation on pre-1980 buildings.[17] Airborne exposure monitoring was conducted as a service to participating contractors and to gather more information on residential and commercial painters' lead exposures.

METHODS AND MATERIALS

Site Selection

The 21 participating painting contractors were encouraged to invite project staff to conduct airborne exposure monitoring during surface preparation work on a pre-1980 building. Twelve contractors extended invitations, and exposure monitoring was conducted for 1 day at each of the 12 job sites during the summer and fall of 1994. The contractor selected the pre-1980 job site and the date of the monitoring. Prior to monitoring, project staff confirmed the presence of detectable lead content in the paint using a sodium rhodizinate colorimetric spot test.

Full-Shift Airborne Lead Exposure Monitoring

The full-shift personal sampling followed National Institute for Occupational Safety and Health (NIOSH) Method 7300 (Elements by ICP), using standard 0.8 μm mixed cellulose ester (MCE) filters.[18] The target airflow rate was 2 L/min. The sampling was conducted in accordance with the requirements of the OSHA Lead in Construction Standard. Laboratory analysis for lead was conducted by the Wisconsin Occupational Health Laboratory (WOHL), part of the Wisconsin State Laboratory of Hygiene. The WOHL was accredited by the American Industrial Hygiene Association Environmental Lead Laboratory Accreditation Program (ELLAP) for lead in air analysis. The limit of quantitation (LOQ) at the target sample volume of 960 L was 0.5 μg/m³.

Short-Term Airborne Lead Exposure Monitoring

Short-term, task-specific exposure monitoring consisted of 30-min samples each measuring the exposure associated with work on one visually uniform paint surface, using one specific surface preparation work method. Task-specific exposure monitoring of exposures to construction workers allows more specificity in assessing the different sources of exposure, and more clearly documents the need for task-specific controls.[19]

These samples were analyzed for both lead and total dust. The lead analysis allowed a comparison of work methods by mean lead exposure levels. However, because this was not a controlled "side-by-side" comparison of different work methods on the same surface, it was expected that this comparison would be confounded by the varying concentration of lead in the different paint surfaces. The intent of analyzing the samples for total dust was to eliminate the confounding effect of different lead paint concentrations. By measuring the "dustiness" of the different work methods, the range of potential airborne lead exposures associated with each work method could be compared directly.

Short-term task-specific sampling was conducted following NIOSH Method 7300, except that 0.8 μm polyvinyl (PVC) membrane filters were used instead of the standard MCE filters. PVC filters were used to allow reliable gravimetric determination of filter weight for total dust analysis. The target airflow rate for these samples was 4 L/min; the target duration was 30 min. Laboratory analysis by WOHL followed NIOSH Method 0500 (Gravimetric total dust) and NIOSH Method 7300.[18] The LOQ for lead at the target sample volume of 120 L was 4 μg/m³; for total dust it was 1250 μg/m³.

Paint Surface Assessment

Bulk samples were collected of each visually uniform paint surface disturbed by the surface preparation work. Bulk paint chip sampling was conducted following the Environmental Protection Agency's (EPA) 1994 guidance document.[20] Laboratory analysis was conducted for lead content by WOHL using in-house methods based on NIOSH Method 7300 (Elements by ICP).[18] WOHL was ELLAP-accredited for lead paint chip analysis.

Duplicate paint chip samples were taken and analyzed colorimetrically to determine which of the accumulated layers of paint contained detectable levels of lead. A handheld magnifying glass, together with Lead Check™ Swabs produced by HybriVet Systems, Inc., Framingham, Mass. were used.[21] The manufacturer reports that the swabs use a rhodizinate reaction to detect the presence of lead above 0.5% (5000 ppm). It should be noted that an EPA/ U.S. Department of Housing and Urban Development (HUD)-funded study of the performance of chemical test kits recommended against their use for lead paint testing.[22]

Frequency of Surface Preparation Methods

As part of the California Painters Project a baseline employer questionnaire was conducted with all 21 participating contractors. The questionnaire assessed the frequency with which contractors used different surface preparation methods on pre-1980 buildings or metal surfaces. For each surface preparation method, the contractor was asked whether the company used the method often, sometimes, or never.

Data Analysis

Airborne exposure data were analyzed using Epi Info Version 5.0.[23] In calculating summary statistics and modeling distributions, all nondetectable results were assigned the value of one-half the limit of detection. All results above the limit of detection, but below the limit of quantitation, were assigned the midpoint value between the limit of detection and the limit of quantitation.

TABLE I. Frequency of Use of Surface Preparation Methods by Painting Contractors

	% of Companies Using Method[A]		
Work Method	Often	Sometimes	Never
Dry manual sanding	90	10	—
Dry manual scraping	86	14	—
Uncontrolled power sanding	38	48	13
Water blasting	38	57	5
Wet scraping	10	33	57
Heat gun	5	43	52
Open flame burning	—	57	43
Abrasive blasting	—	10	90
HEPA-exhausted power sanding	—	5	95

[A]N = 21.

RESULTS

Frequency of Surface Preparation Methods

The contractor responses regarding the frequency with which their company used different surface preparation methods are summarized in Table I. The most frequently used methods were dry manual sanding, with 90% of the contractors reporting that they used it often; and dry manual scraping, with 86% of the contractors reporting they used it often. Other frequently used work methods were uncontrolled power sanding (the use of a power sander that is not equipped with a vacuum attachment) and water blasting, with 38% reporting that they used these methods often.

Full-Shift Airborne Lead Exposures

In total, 25 full-shift samples were collected at 11 of the 12 job sites, each sample from a different employee. The samples represent work on 18 visually uniform paint surfaces. The lead paint concentrations of these surfaces ranged from 0.04 to 42%. Analyses by rhodizinate spot test showed that the top layer of 3 of the 18 surfaces contained detectable lead content; all of the remaining surfaces contained detectable lead only in the underlying paint layers.

The results of the 25 full-shift samples, when calculated as 8-hr time-weighted averages (8-hr TWAs), ranged from 0.8 to 550 $\mu g/m^3$. The arithmetic mean was 57 $\mu g/m^3$, above the OSHA permissible exposure limit (PEL) of 50 $\mu g/m^3$ (GM = 18 $\mu g/m^3$, GSD = 3.7).

Six of the 25 samples (24%) were above the OSHA PEL. All 6 of the samples that exceeded the PEL represented work shifts that involved dry manual sanding or uncontrolled power sanding, whereas only 9 of the 19 sample results below the PEL represented work shifts that involved use of these methods. The 2 highest full-shift air samples (310 and 550 $\mu g/m^3$) were the result of dry manual sanding on a surface that tested 18% lead and contained detectable lead in the top layer of paint.

TABLE III. Mean 30-Minute Lead Exposures ($\mu g/m^3$), by Percentage Lead in Paint and Work Method

	Bulk Lead Paint Concentration (%)		
Work Method	0–9.9% (n)	10–19.9% (n)	20–45% (n)
HEPA-exhausted power sanding	24 (2)	52 (2)	26 (3)
Dry scraping	25 (6)	94 (12)	—
Dry manual sanding	53 (3)	600 (6)	—
Uncontrolled power sanding	97 (4)	900 (6)	—

Short-Term Airborne Lead Exposures

Fifty-eight 30-min task-specific samples were collected at 11 of the 12 job sites, from 25 different employees. The samples represent work on 20 visually uniform paint surfaces. The lead paint concentrations of these surfaces ranged from 0.04 to 23%. Analyses by rhodizinate spot test showed that the top layer of 3 of the 20 surfaces contained detectable lead content; all of the remaining surfaces contained detectable lead only in the underlying paint layers.

The 30-min lead exposure results by work method are presented in Table II. The arithmetic mean results for heat gun, wet sanding, and open flame burning were below 10 $\mu g/m^3$. The mean result for HEPA-exhausted power sanding was 33 $\mu g/m^3$; the mean result for dry manual scraping was 71 $\mu g/m^3$. In comparison, the mean results for dry manual sanding (420 $\mu g/m^3$) and uncontrolled power sanding (580 $\mu g/m^3$) were much higher.

To partially address the confounding effect of varying lead paint content, Table III provides results for the same data for four work methods categorized by the percentage of lead in the paint being removed. This allows a better comparison of the lead exposures associated with these methods.

The nine 30-min samples for dry manual sanding were taken at three different work sites; at each site, three samples were taken on an individual worker while he or she worked on one visually uniform paint surface. A distribution of potential full-shift exposures was modeled for work at each work site. It was assumed that the underlying distribution of 30-min TWAs for the task was lognormal and, based on the three sample results, geometric mean and geometric standard deviation values were estimated. These values were used to simulate distributions of 8-hr TWAs based on

TABLE II. Thirty-Minute Lead Exposures by Work Method ($\mu g/m^3$)

Work Method	n	Range	Arithmetic Mean	Geometric Mean	Estimated 95%tile Value[A]
Heat gun	6	<1 (n.d.) − 5	2.3	—	—
Wet sanding	3	<1 (n.d.) − 7	3.3	—	—
Open flame burning	5	<4 (n.d.) − 20	9.8	—	—
HEPA-exhausted power sanding	7	4 − 60	33	23	130
Dry scraping	18	≤4 − 230	71	38	340
Dry manual sanding	9	29 − 1200	420	220	2100
Uncontrolled power sanding	10	65 − 3400	580	220	1700

[A]95%tile value estimated based on lognormal distribution.

TABLE IV. Estimated Distributions of Full-Shift Lead Exposures while Dry Manual Sanding: Proportion (%) Exceeding 500 μg/m³ by Work Site and Duration of Task

Work Site (% Lead in Paint)[A]	Duration of Dry Manual Sanding 2 hr	4 hr	6 hr
Site 10: (0.14%, 0.06%)	0	0	0
Site 07: (14%, 6.7%)	0.57	3.5	15
Site 12: (17%, 20%)	<0.01	9.5	98

[A]Results of both bulk samples taken on paint surface (% wt/wt).

TABLE V. Thirty-Minute Total Dust Exposures by Work Method (μg/m³)

Work Method	n	Mean Total Dust	SD
HEPA-exhausted power sanding	7	1600[A]	2000
Dry scraping	17	1100[B]	720
Dry sanding	9	6700	3600
Uncontrolled power sanding	10	14,000	13,000

[A]Six sample results were below the limit of quantitation; therefore, mean value is estimated.
[B]Ten sample results were below the limit of quantitation; therefore, mean value is estimated.

a worker performing alternately 2, 4, and 6 hours of sanding during a workday, and having no exposure during the remainder of the shift.[24] To illustrate: For the 30-min exposures at Site 7 the estimated geometric mean is 290 μg/m³ and the estimated geometric standard deviation is 2.8; the corresponding task arithmetic mean estimate is 430 μg/m³. To simulate an 8-hr TWA involving 6 hr of dry sanding, twelve 30-min TWA values were selected from this distribution and the full-shift exposure was calculated assuming zero exposure for the remainder of the shift. One hundred thousand 8-hr. TWAs were simulated in this manner to obtain a stable distribution of 8-hr TWA values.

The results of this modeling are presented in Table IV. The percentage of modeled 8-hr TWAs greater than 500 μg/m³ are presented for the worker at each of the three work sites. The percentage of exceedance of 500 μg/m³ is of interest because this represents the proportion of full-shift exposures at the job site that would exceed the OSHA maximum use concentration for a half-mask respirator.

Of the fifty-eight 30-min samples taken, 57 samples were analyzed gravimetrically (an MCE filter was inadvertently used for one of the samples and therefore could not be analyzed gravimetrically). The mean gravimetric results for the four dustiest work methods are presented in Table V.

The 27 samples with quantifiable total dust results represented in Table V also had quantifiable lead results. For these samples the percentage of lead in the total dust collected on the filter was calculated. Figure 1 is a scattergram of these 27 samples, plotting the percentage of lead in the paint (x-axis) versus the percentage of lead in the filter dust (y-axis). Data for the four work methods (HEPA-exhausted power sanding, uncontrolled power sanding, dry manual sanding, and dry scraping) are combined on this graph. The Spearman's rank correlation coefficient for these 27 points is $r_s = 0.543$ ($p<0.05$). The 1:1 ratio line is superimposed on the scattergram for illustration purposes.

DISCUSSION

These results measure airborne lead exposures associated with the exterior surface preparation work of 12 skilled residential and commercial painting contractors operating in the San Francisco Bay area. Although they derive from a relatively small number of samples, the results suggest several conclusions relevant to painters' risks during surface preparation.

There is only a small number of other data sources with which these results can be compared: an unpublished study by the California Department of Health Services of 28 painters who restored Victorian houses in San Francisco;[2] data collected by D.E. Jacobs of employee exposures on lead-based paint abatement projects;[10] data presented in the *Federal Register* by OSHA in support of the Final Interim Lead in Construction Standard;[5] a report from the Washington State Department of Labor and Industries of five visits to painting jobs at pre-1950 homes;[9] and the EPA-sponsored study of remodeling and renovation workers that included air monitoring during paint removal.[8] The validity of any comparison between these different sets of exposure data is somewhat limited by the fact that, in many instances, they often represent different exposure durations.

Full-Shift Lead Exposures

The full-shift exposure data clearly show that 8-hr TWA lead exposures of residential and commercial painters can exceed the OSHA PEL of 50 μg/m³ during exterior surface preparation work on lead paint surfaces. Sometimes exposures can be very high, greatly exceeding the PEL. Similar findings have been reported previously in the literature.

The data presented here also indicate that the higher full-shift exposures are associated with the use of dry manual sanding or uncontrolled power sanding. Of the 15 full-shift samples that involved dry manual sanding or uncontrolled power sanding 6 samples (40%) exceeded 50 μg/m³. One sample (7%) exceeded 500 μg/m³ (550 μg/m³) or the maximum full-shift exposure level (10 × PEL) for which half-mask respirators provide adequate protection as per the OSHA Lead in Construction Standard (29 CFR §1926.62). These results are cause for concern because both of these surface preparation methods are commonly used by residential and commercial painters (see Table I), and half-mask respirators are widely used as the sole protection against the airborne lead dust. This concern is supported by the 30-min task-specific exposure results for both dry manual sanding and uncontrolled power sanding.

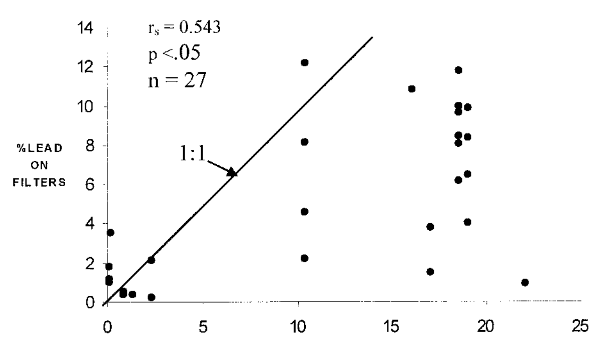

FIGURE 1. Percentage lead in paint versus percentage lead on air sample filter

Dry Manual Sanding and Power Sanding

The analysis of the fifty-eight 30-min samples (Table II) shows that particularly high mean airborne lead exposures were associated with dry manual sanding (420 μg/m³) and uncontrolled power sanding (580 μg/m³). In fact, the mean 30-min lead exposures for these two methods were an order of magnitude higher than those for the other methods. This finding is consistent with the full-shift results.

This study's 30-min sample results for dry manual sanding (range: 29–1200 μg/m³; mean: 420 μg/m³; GM: 220 μg/m³; estimated 95th percentile: 2100 μg/m³) are in general agreement with exposure levels found in previous studies. In the EPA study 6 samples taken during hand scraping and sanding had a geometric mean TWA of 254 μg/m³ and an estimated 95th percentile of 1410 μg/m³. EPA's study also included a meta-analysis of data from six unpublished sources involving surface preparation primarily by dry hand sanding and scraping. Based on 31 samples from interior work, the geometric mean exposure was 58 μg/m³, with an estimated 95th percentile of 6350 μg/m³; 38 samples from similar exterior work showed a geometric mean of 4.3 μg/m³ and an estimated 95th percentile of 114 μg/m³.

In the OSHA Lead in Construction Standard, manual sanding is listed as a work method that, in the absence of previous exposure data, is initially presumed to expose employees to lead in excess of 50 μg/m³ but not in excess of 500 μg/m³. However, the arithmetic mean for the nine 30-min exposures in this study was 430 μg/m³ and four of the nine results exceeded 500 μg/m³. Using these nine 30-min sample results to model three site-specific distributions of 8-hr TWAs indicates that a significant proportion of the full-shift exposures would exceed 500 μg/m³ (Table IV). This indicates that it is common for dry manual sanding to result in full-shift lead exposure levels that exceed 10 times the PEL, the OSHA maximum exposure level for which half-mask air-purifying respirators may be used.

This study's ten 30-min sample results for uncontrolled power sanding (range: 65–3400 μg/m³; mean: 580 μg/m³; GM: 220 μg/m³; estimated 95th percentile: 1700 μg/m³) generally agree with the small amount of data available from previous studies. In the EPA study, three personal samples involving power sanding had a geometric mean of 571 μg/m³ and an estimated 95th percentile of 3170 μg/m³. In the Washington State study, three painters doing power sanding had TWA exposures of 400, 1035, and 2270 μg/m³. The highest TWA exposure in the San Francisco Victorian study, 1700 μg/m³, was measured during power sanding.

In the exposure assessment data assembled by OSHA in support of the Lead in Construction Standard, 65 samples taken during nonabatement power tool use ranged from 1 to 20,600 μg/m³, with a mean of 735 μg/m³ and an estimated 95th percentile value of 1314 μg/m³.[5] The ten 30-min sample results from this study had an estimated 95th percentile value of 1700 μg/m³. This lends support to OSHA's decision to list "power tool cleaning without dust collection systems" as a work method that, in the absence of exposure monitoring, should be treated as exposing employees to lead in excess of 500 μg/m³ but not in excess of 2500 μg/m³. The fact remains, however, that the painters monitored by this project were not wearing full-face respirators but rather half-mask respirators during this work and that this kind of respirator is widely used among residential and commercial painters. The data indicate that it is common for uncontrolled power sanding to result in 30-min lead exposure levels that, if sustained for a full work shift, would exceed 10 times the PEL, the OSHA maximum exposure level for which half-mask air-purifying respirators may be used.

The 30-min results in Table II for dry manual sanding and uncontrolled power sanding are roughly equivalent in terms of worker lead exposure. In Table III these same results are categorized by the percentage of lead in the paint so as to partially adjust for the confounding effect of this variable. The results in Table III show that the mean lead exposures from uncontrolled power sanding are higher than for dry manual sanding when the two methods are used on paint surfaces with approximately the same lead content (900 vs. 600 μg/m³, and 97 vs. 53 μg/m³).

By analyzing the amount of total dust exposure associated with these two methods, their relative "dustiness" can be compared. Samples were analyzed for total dust to compare work methods while avoiding the confounding effect of different lead paint concentrations. By measuring the dustiness of the two work methods, the range of potential airborne lead exposures associated with each method could be compared directly. The data in Table V indicate that the mean total dust exposure level for power sanding (14,000 μg/m³) was twice that of dry manual sanding (6700 μg/m³).

In summary, the results indicate that dry manual sanding and uncontrolled power sanding can both result in high airborne lead exposures among residential and commercial painters. The data also indicate that exposures from uncontrolled power sanding can be expected to be approximately twice that of dry manual sanding. Both methods can result in lead exposure levels that, if sustained for a full work shift, would exceed 10 times the PEL (500 μg/m³ as an 8-hr TWA) and thus the OSHA-assigned level of protection for a half-mask air-purifying respirator. This finding supports the full-shift exposure results discussed previously. Together these findings indicate that painters are not always adequately protected by half-mask respirators when dry manual sanding or using uncontrolled power sanding on lead-containing paint.

HEPA-Exhausted Power Sanding

Airborne exposures associated with dry manual sanding, uncontrolled power sanding, and HEPA-exhausted power sanding are provided in Tables II and III. The results in Table II indicate that the mean 30-min exposure level associated with HEPA-exhausted power sanding is 8% of the mean level for dry manual sanding and 6% of the mean level for uncontrolled power sanding. The results in Table III provide exposure levels for the three methods given paint concentrations that fall within the same range.

For the paint concentration range of 10–19.9% lead, the mean exposure level associated with HEPA-exhausted power sanding (52 μg/m³) is 9% of that associated with dry manual sanding (600 μg/m³) and 6% of that associated with uncontrolled power sanding (900 μg/m³). For the paint concentration range of 0–9.9% lead, the mean exposure level associated with HEPA-exhausted power sanding (24 μg/m³) is 45% of that associated with dry manual sanding (53 μg/m³) and 25% of the level associated with uncontrolled power sanding (97 μg/m³).

As discussed above, the intent of simultaneously analyzing the samples for "total dust" exposures was to compare work methods independent of differences in surface lead paint concentration. The data in Table V indicate that the estimated mean total dust exposure for HEPA-exhausted power sanding is 1600 μg/m³ or 24% of the level for dry manual sanding (6700 μg/m³) and 11% of the level for uncontrolled power sanding (14,000 μg/m³).

In summary, the data indicate that airborne lead exposures from HEPA-exhausted power sanding can be expected to be approximately 20% of the levels from dry manual sanding and 10% of the levels from uncontrolled power sanding.

It should be kept in mind that this is not a rigorous comparison; it is not based on a staged side-by-side use of the different methods to remove the same mass of paint containing the same percentage weight of lead. This lack of strict methodological control somewhat weakens the case for substitution. On the other hand, this comparison is based on sampling of painters' autonomous work including the use of a variety of tools, by different painters, under a variety of job site conditions. As such, these are likely reasonable estimates of the amount of exposure control that can be expected from HEPA-exhausted power sanders as employed by painting contractors in the field.

At the beginning of the project only 5% of the participating contractors reported that they "sometimes" used HEPA-exhausted power sanding (Table I); the work method is clearly not widely used among residential and commercial painters. However, given the data above indicating that full-shift lead exposures from both dry manual sanding and uncontrolled power sanding can often exceed 500 μg/m³, HEPA-exhausted power sanding should be more widely promoted as an alternative work method that can reduce exposures by 80 to 90%.

Heat-Based Methods

Other researchers have found higher exposures associated with the use of heat-based methods—removing paint using heat guns or open flame burning. The six heat gun 30-min sample results ranged from none detected to 5 μg/m³, with a mean of 2.3 μg/m³ (Table II). In a NIOSH study of abatement workers using heat guns for interior paint removal, 10 personal samples ranged from none detected to 286 μg/m³, with 6 samples (60%) exceeding 50 μg/m³. Three additional samples during exterior work were much lower (none detected to 3 μg/m³). NIOSH concluded that workers using heat guns are potentially overexposed to lead.[3]

The five 30-min open flame burning sample results ranged from none detected to 20 μg/m³, with a mean of 9.8 μg/m³ and median value of 8.0 μg/m³ (Table II). The San Francisco Victorian study,[2] which primarily involved monitoring during open flame burning, reported a median air lead concentration of 75 μg/m³, higher than the level found in this study. Jacobs reported two sample results for a propane torch operator as 4260 μg/m³ and 10,960 μg/m³.[10]

Because of concerns about lead fume generation, the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* prohibits the use of open flame burning and also heat guns unless temperatures are controlled to under 1100°F.[25] This study did not show high airborne exposures associated with heat-based tasks. However, a very small number of samples was collected, and they are not of themselves sufficient to allow any conclusions to be drawn.

Effect of Lead Paint Concentration on Airborne Lead Exposures

The data presented in Table III indicate that higher lead paint concentrations were associated with higher mean airborne lead exposures. For the twenty-seven 30-min samples that resulted in both quantifiable lead and total dust results, it was possible to look directly at the correlation between the concentration of lead in the paint and in the airborne dust collected on the filter (Figure 1). The p-value associated with the Spearman's rank correlation coefficient demonstrates a modest but statistically significant correlation between the two percentages—as the percentage of lead in the disturbed paint surface rises, the percentage of lead in the airborne dust also increases. However, the scatter of points suggests, and it is logical to expect, that the relationship between these two percentages will vary depending on other factors, including the degree of paint surface and substrate disturbance and the location of the lead-containing paint layers relative to the surface. The 1:1 ratio has been drawn on the graph to show that, as a general rule, the points tend to fall below the line; the percentage of lead in the airborne dust was in most instances less than the percentage of lead in the surface paint. This may in part have been due to the fact that lead tended to be concentrated in the underlying older layers of paint. Of these twenty-seven 30-min air samples, 18 represent work that was done on surfaces where the top layer of paint was shown not to be lead containing. Underlying layers of lead paint were less likely to be disturbed by the work and therefore to contribute to the airborne particulate. Conversely, where underlying lead paint layers were disturbed, disturbance of the substrate material could have diluted the lead content of the airborne particulate.

CONCLUSIONS AND RECOMMENDATIONS

The full-shift exposure data clearly show that 8-hr TWA lead exposures among residential and commercial painters can exceed the OSHA PEL of 50 μg/m³ during exterior surface preparation work on lead paint surfaces.

In general, the data support the premise that painters' airborne lead exposures depend both on the surface preparation method being used and the amount of lead in the paint. The "dustier" the surface preparation method and the higher the concentration of lead in the paint, the higher the airborne lead exposure will be.

The full-shift data indicate that the higher exposures are associated with the use of dry manual sanding or uncontrolled power sanding. Analysis and modeling based on the 30-min sample results indicate that painters are often not adequately protected by half-mask respirators when dry manual sanding or using uncontrolled power sanding on lead-containing paint. These results are cause for concern because both of these surface preparation methods are widely used, and half-mask respirators are commonly used as protection. The data indicate that HEPA-exhausted power sanding, as employed by painting contractors in the field, reduces paint dust exposures by approximately 80 to 90%. The use of these tools should be more widely promoted as a safer alternative when sanding on lead-containing paint.

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REFERENCES

1. **U.S. Department of Housing and Urban Development:** *Comprehensive and Workable Plan for the Abatement of Lead-Based Paint in Privately Owned Housing. Report to Congress.* Washington, DC: U.S. Department of Housing and Urban Development, 1990.
2. **California Department of Health Services:** "Technical Report: Lead Exposures Associated with Paint Removal from Victorian-Style Houses in the San Francisco Bay Area." 1993. California Department

APPLIED STUDIES

of Health Services, Childhood Lead Poisoning Prevention Program, 1515 Clay St., Suite 1801, Oakland, CA 94612.

3. **National Institute for Occupational Safety and Health (NIOSH):** *Health Hazard Evaluation Report: HUD Lead-Based Paint Abatement Demonstration Project* (HETA 90-070-2181). Cincinnati, OH: NIOSH, 1992.
4. **National Institute for Occupational Safety and Health (NIOSH):** *Health Hazard Evaluation Report: People Working Cooperatively* (HETA 93-0818-2646) Cincinnati, OH: NIOSH, 1997.
5. "Lead Exposure in Construction," *Federal Register 58*:84 (4 May 1993). p. 26612.
6. **Sussell A., J. Gittleman, and M. Singal:** Worker lead exposure during renovation of homes with lead-based paint. *Appl. Occup. Environ. Hyg. 13*:770–775 (1998).
7. **Sussell, A., C. Hart, D. Wild, and K. Ashley:** An evaluation of worker exposures and cleaning effectiveness during removal of deteriorated lead-based paint. *Appl. Occup. Environ. Hyg. 14*:177–185 (1999).
8. **U.S. Environmental Protection Agency (EPA):** *Lead Exposure Associated with Renovation and Remodeling Activities: Environmental Field Sampling Study,* vol. 1. Washington, DC: EPA, 1997.
9. **Washington State Department of Labor and Industries:** *Exposure Assessment Among Residential Painters Occupationally Exposed to Lead* (Technical report 37–11–1995). Olympia, WA: Washington State Department of Labor and Industries, 1995.
10. **Jacobs, D.E.:** Occupational exposures to lead-based paint in structural steel demolition and residential renovation work. *Int. J Environ. Pollut. 9*:126–139 (1998).
11. **Feldman, R.G.:** Urban lead mining: Lead intoxication among deleaders. *N. Engl. J Med. 298*:1143–1145 (1978).
12. **Amitai, Y., J.W. Graef, M.J. Brown, R.S. Gerstle, N. Kahn, and P.E. Cochrane:** Hazards of "deleading" homes of children with lead poisoning. *Am. J. Dis. Child 141*:758–760 (1987).
13. **Spaedy, S., and T.T. Schubert:** Inorganic lead poisoning in an adult. *Am. J. Gastroenterol. 83*:581–583 (1988).
14. **Schneitzer, L., H.H. Osborn, A. Bierman, A. Mezey, and B. Kaul:** Lead poisoning in adults from renovation of an older home. *Ann. Emerg. Med. 19*:415–420 (1990).
15. **Waller, K., A.M. Osorio, N. Maizlish, and S. Royce:** Lead exposure in the construction industry: Results from the California Occupational Lead Registry, 1987 through 1989. *Am. J. Public Health 82*:1669–1671 (1992).
16. **Rabin, R., D.R. Brooks, and L.K. Davis:** Elevated blood lead levels among construction workers in the Massachusetts Occupational Lead Registry. *Am. J. Public Health 84*:1483–1485 (1994).
17. **California Department of Health Services:** *California Painters Project: Helping Small Business Work Safely with Lead*. Berkeley, CA: California Department of Health Services, 1998.
18. **National Institute for Occupational Safety and Health (NIOSH):** *NIOSH Manual of Analytical Methods,* 4th ed. Cincinnati, OH: NIOSH, 1994.
19. **Goldberg, M., S.M. Levin, J.T. Doucette, and G. Griffin:** A task-based approach to assessing lead exposure among iron workers engaged in bridge rehabilitation. *Am. J. Ind. Med. 31*:310–318 (1997).
20. **U.S. Environmental Protection Agency (EPA):** *Guidance for Measuring Lead in Soil and Paint*. Washington, DC: EPA, 1994.
21. **Occupational Safety and Health Administration (OSHA):** *Lead Test Kits, Product Evaluation* (PE-14). Salt Lake City, Utah: OSHA Technical Center, 1994.
22. **U.S. Environmental Protection Agency (EPA):** *A Field Test of Lead-Based Paint Testing Technologies.* Washington, DC: EPA, 1995.
23. **Dean, A.G., J.A. Dean, A.H. Burton, R.C. Dicker:** *Epi Info,* version 5 [Software]. Atlanta: Centers for Disease Control and Prevention, 1990.
24. **Nicas, M., and R.C. Spear:** A task-based statistical model of a worker's exposure distribution: Part I—description of the model. *Am. Ind. Hyg. Assoc. J. 54*:221–220 (1993).
25. **U.S. Department of Housing and Urban Development (HUD):** *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing.* Washington, DC: HUD, 1995.